

INDIAN OCEAN AND TAIWAN RAINFALLS SET NEW RECORDS

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ABSTRACT

Recently obtained information on rainfall maxima on the island of La Réunion, about 400 mi. east of Madagascar, established new records for durations from 9 hr. to 8 days. Some of the previous record values for 15 to 24 hr. were exceeded also by Taiwan rainfalls, which were, however, of much lower magnitude than those at La Réunion. World-record values for durations from 1 min. to 2 yr. are listed. The envelope curve of these maxima may be defined by the expression $R = 16.6 D^{0.475}$, where R is rainfall in inches and D is duration in hours.

1. INTRODUCTION

Some recently uncovered information on heavy rainfalls on the island of La Réunion revealed several amounts far surpassing those previously accepted as world-record values for durations from 9 hr. to 8 days. The former world-record values for 15 to 24 hr. were also exceeded by rainfall amounts observed at Taiwan in 1963. The Taiwan values were much less than those observed at La Réunion, but were especially notable in that they were measured in recording gages, thus adding to the degree of confidence in the reliability of the observations and, at the same time, providing information on the chronological distribution of rainfall associated with the passage of a typhoon. They are also still the highest known values observed in the Northern Hemisphere.

2. THE LA RÉUNION RAINFALLS

The island of La Réunion, located about 400 mi. east of Madagascar in the Indian Ocean, is about 30 by 40 mi. and is extremely mountainous with elevations reaching up to slightly over 10,000 ft. m.s.l. (fig. 1). Its extremely steep slopes and numerous rapidly narrowing valleys are ideal for the production of heavy rainfall when wind directions favor upslope and up-valley motion.

The rainfall of the island is greatly influenced by tropical cyclones, all but a few occurring during the November-May season with the January-April period being the most favorable. The heavy rainfalls associated with tropical storms are greatly intensified by the orographic influences, and amounts that would be considered phenomenal by ordinary standards are apparently relatively common for the island.

Table 1 lists 1- to 8-day rainfall maxima for three stations that have each measured over 60 in. in 24 hr. (observational day). It should be noted that these amounts were all observed within the relatively short 13-yr. period, 1952-1964. All amounts were obtained from official observations, and were confirmed by corre-

TABLE 1.—Some extraordinary rainfall maxima at La Réunion

Station: Lat. and long.: Elev:	Aurere 21°00' S., 55°26' E. 940 m. (3084 ft.)		Belouve 21°03' S., 55°33' E. 1500 m. (4921 ft.)		Cilaos 21°07' S., 55°29' E. 1200 m. (3937 ft.)	
Duration (days)	Amount (in.)	Date	Amount (in.)	Date	Amount (in.)	Date
1.....	62.33	4/7-8/58	66.49	2/27-28/64	73.62	3/15-16/52
2.....	97.12	4/7-9/58	95.09	2/27-29/64	98.42	3/15-17/52
3.....	123.21	4/6-9/58	105.90	2/26-29/64	127.56	3/15-18/52
4.....	134.74	4/5-9/58	109.50	2/26-31/64	137.95	3/14-18/52
5.....	136.83	4/4-9/58	110.22	2/25-31/64	151.73	3/13-18/52
6.....	136.83	4/4-9/58	110.58	2/24-31/64	159.65	3/13-19/52
7.....	136.83	4/4-9/58	112.04	2/26-3/4/64	161.81	3/12-19/52
8.....	136.83	4/4-9/58	118.54	2/26-3/5/64	162.59	3/11-19/52

spondence with the French Meteorological Service. The amounts for Aurere and Cilaos were obtained from a survey of about 6 yr. of published data. The Belouve measurements were volunteered in a communication from the French Meteorological Service. Since the phenomenal amounts of table 1 were the result of an incomplete survey of a short period of record, there is a good chance that a more thorough survey of a longer period of record would disclose other, and perhaps even greater, amounts of similar magnitude. Table 2 shows the chronological distribution of the maximum 1-day amount of 66.49 in. observed at Belouve. The information was reported in a letter from the French Meteorological Service, and revealed that the 1-day amount actually fell in 18.5 hr. This 66.49 in. amount exceeded the previous world record 24-hr. value of 45.99 in. at Baguio, Philippines [1] by 20.50 in.

TABLE 2.—Chronological distribution of maximum 1-day amount observed at Belouve

Duration (hr.)	Amount (in.)	Time (LST)	Date
2.....	15.18	1300-1500	2/28/64
6.....	30.16	1300-1900	2/28/64
9.....	42.79	1300-2200	2/28/64
12.....	52.76	1300-0100	2/28-29/64
18.5.....	66.49	1300-0730	2/28-29/64

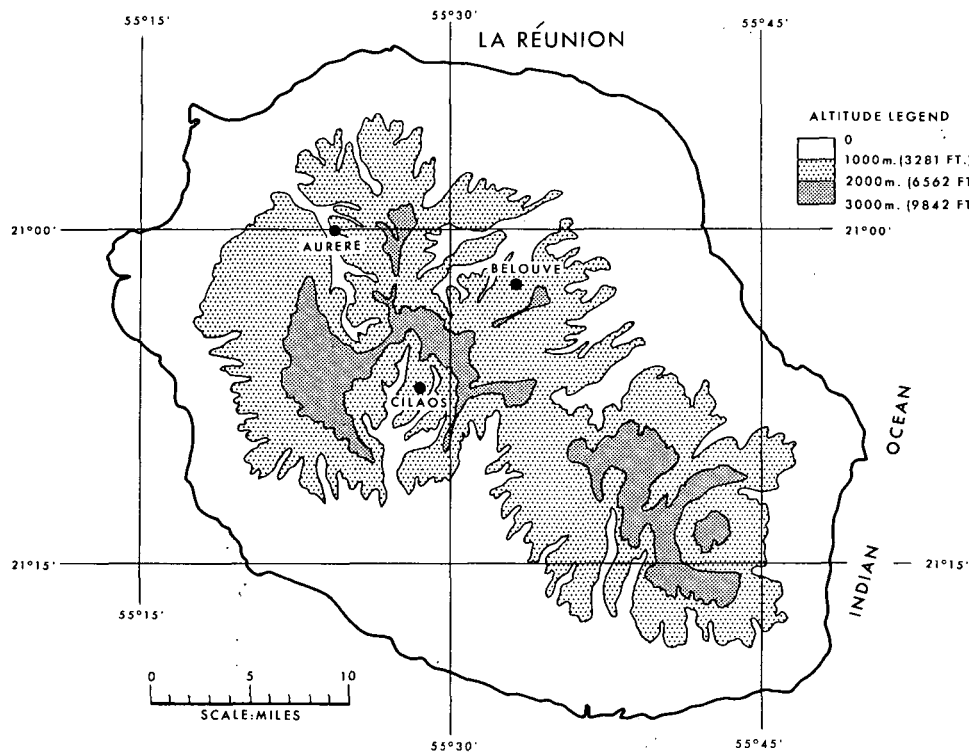


Figure 1.—La Réunion.

Little is known of the meteorological situations associated with the rainfalls of table 1. The amounts given for Cilaos were associated with a tropical cyclone that reportedly [2] formed between the islands of Tromelin (16° S., 54° E.) and Ste. Marie (17° S., 50° E.), about 400 mi. northwest of La Réunion, then moved southeastward, passing during the period March 15–20 within 100 mi. southwest of the island. La Réunion experienced outstanding floods that wreaked havoc. This trajectory is typical for tropical storms in this area at this time of the year [3].

The lack of detailed information on the track of the storm and the timing of its movement precluded analysis of the orographic influences contributing to the outstanding rainfall amounts observed. The clockwise circulation (Southern Hemisphere) in the tropical cyclone presumably resulted in general northerly to westerly winds on La Réunion at about the time the center was approaching or was closest to the island. If the record rainfall at Cilaos (elev. 3937 ft.), which lies on the lee side of the main divide for the island, about 2 to 3 mi. from the crest (fig. 1), occurred while such wind directions prevailed, one can conclude only that much of the rainfall resulted from an unusually potent spill-over effect or perhaps from the funneling effect of sharply narrowing valleys on localized up-valley wind components.

If the rains at Cilaos occurred as the cyclone was receding from the island, the southwesterly and southerly winds blowing upslope and up the valleys on the south

side of the island appear to provide a more favorable situation for the outstanding amounts.

The meteorological situations associated with the rainfall maxima for Aurere and Belouve, which lie on the northern slopes, are unknown, but it may be reasonably presumed that they were tropical cyclones also since these maxima were observed at the height of the tropical storm season.

3. THE TAIWAN RAINFALLS

In Taiwan (Formosa) Halaho and Paishih, two precipitation stations about 13 mi. apart equipped with recording gages, measured outstanding intensities during the unusually heavy rains of September 9–12, 1963, in connection with the passage of typhoon Gloria [4]. The Paishih measurements exceeded values then accepted as world records for durations from 15 to 24 hr. The locations of the two stations, as well as the track of typhoon Gloria during the period of heavy rains, are shown in figure 2.

Halaho is located at an elevation of 1160 m. (3806 ft.) near the source of a mountain stream flowing in a general northwestward direction down the western slope of the main ridge dividing the island drainage into east and west. Halaho sits near the ridge, which takes the form of a col, or saddle, in that vicinity. The station is thus in a favorable location to receive heavy precipitation from the lifting effect of both the upslope westerly winds and funneling of the air through the saddle. Easterly winds may also cause heavy precipitation since Halaho is so

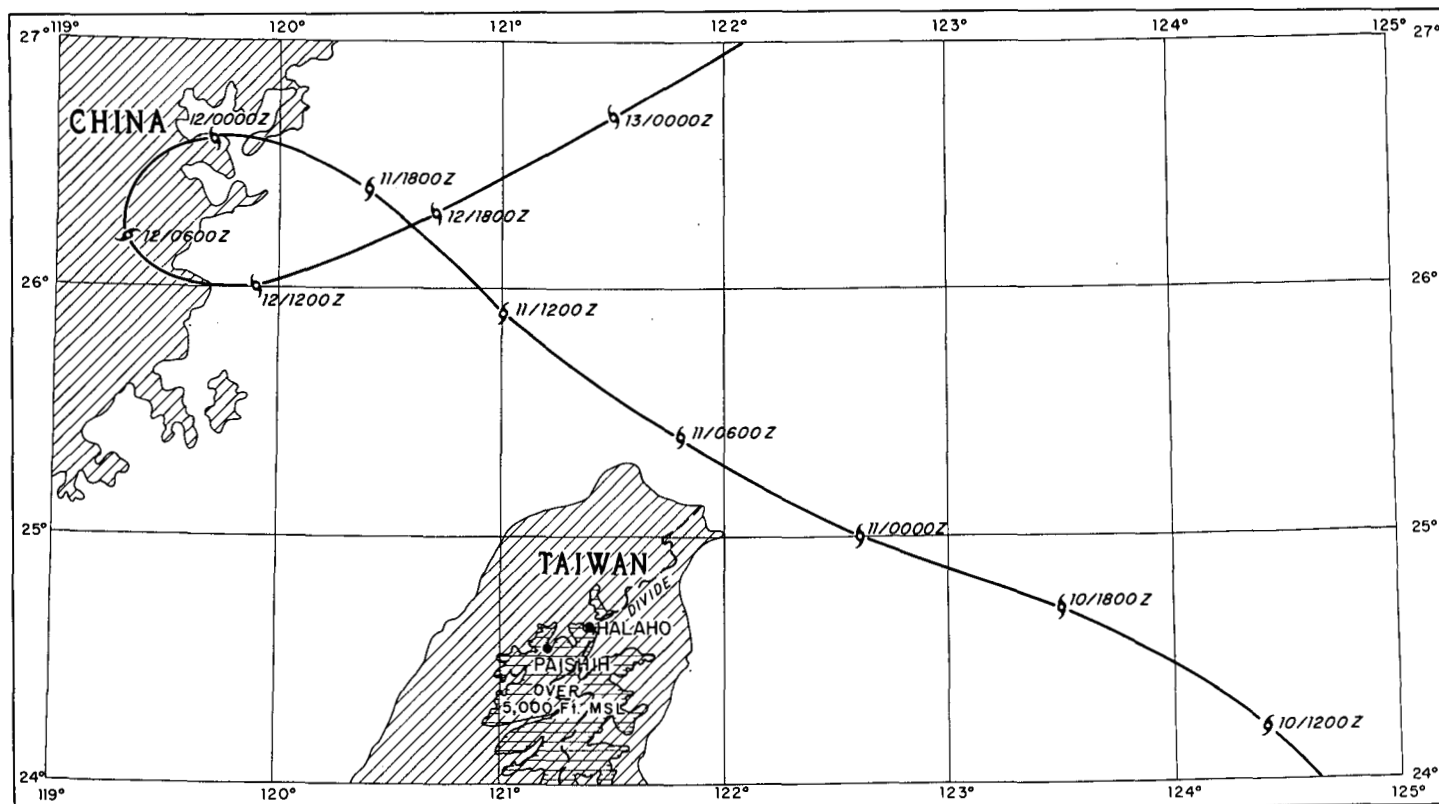


Figure 2.—Path of typhoon *Gloria* during the period 1200 GMT, September 10, to 0000 GMT, September 13, 1963. Period of maximum 24-hr. rainfall at Paishih was from 1200 GMT, September 10 to 1200 GMT, September 11, and of maximum 12-hr. rainfall from 1800, September 10, to 0600 GMT, September 11, 1963.

near the ridge that it probably receives a great deal of precipitation formed in moist air lifted up the eastern slope but spilled over the ridge onto the western slopes. However, the winds at the time Halaho experienced its greatest intensities (table 3) in connection with typhoon *Gloria* were probably northerly to westerly.

Paishih is also on the western slope of the main divide. It is at an elevation of 1636 m. (5,368 ft.) near the headwaters of a mountain stream flowing in a general north-eastward direction. Northerly winds would thus blow up the valley. The station is sheltered to the east and west by ridges of over 7,000 ft. (fig. 2). The ridge to the west is apparently only about 1 mi. away, and the station probably gets a great deal of spill-over precipitation associated with westerly winds. Much of the heavy rain observed in connection with typhoon *Gloria* probably resulted from spill-over and from the funneling effect of up-valley winds.

The mass rainfall curves (fig. 3) for Halaho and Paishih are very similar. Paishih experienced greater intensities at the height of the storm on September 11, but the total storm rainfalls at the two stations differed by only 0.01 in., i.e., 66.29 and 66.30 in. The maximum amounts for durations from 1 to 48 hr. are shown in table 3.

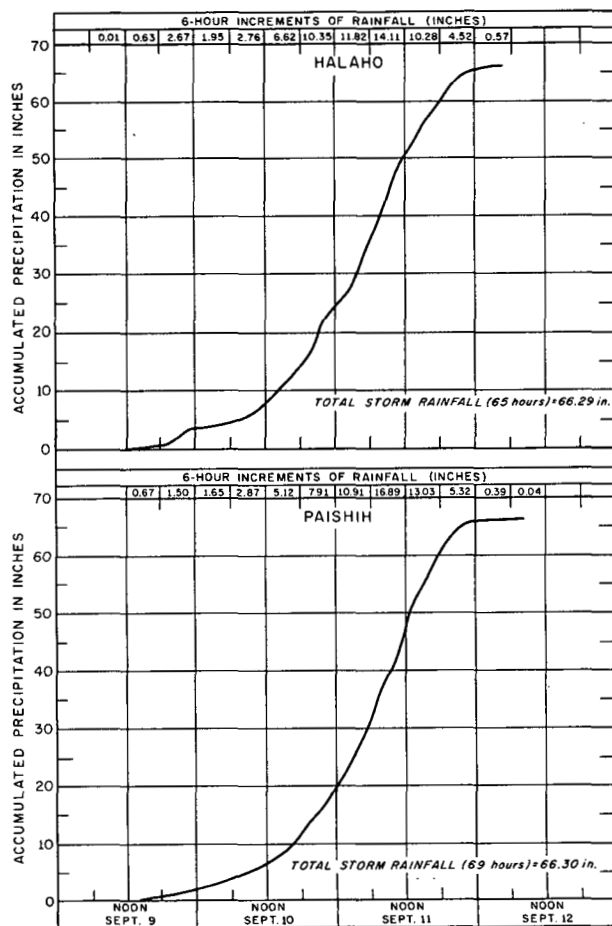


Figure 3.—Mass rainfall curves for Halaho and Paishih.

TABLE 3.—Maximum rainfall amounts for durations to 48 hours at Halaho and Paishih

Duration (hr.)	Amount (in.)	Date (Sept. 1963) and Time (120th E. Mer.)
Halaho (24°38' N., 121°24' E.; elev. 3,806 ft.)		
1.....	3.08	11/0800-0900
3.....	8.15	11/0800-1100
6.....	15.33	11/0300-0900
12.....	27.59	11/0300-1500
18.....	37.58	10/1900-11/1300
24.....	46.98	10/1700-11/1700
30.....	53.53	10/1400-11/2000
36.....	58.69	10/0900-11/2100
48.....	63.14	9/2100-11/2100
Paishih (24°33' N., 121°13' E.; elev. 5,368 ft.)		
1.....	3.58	11/0700-0800
3.....	9.13	11/1000-1300
6.....	17.20	11/0700-1300
12.....	30.35	11/0200-1400
18.....	41.34	11/0100-1900
24.....	49.13	10/2000-11/2000
30.....	56.34	10/1400-11/2000
36.....	60.00	10/0900-11/2100
48.....	63.78	9/2300-11/2300

At least one Taiwan station received greater total storm rainfall than either Halaho or Paishih. For the period September 9-12, Paling [4] reported daily amounts of 9.64, 41.10, 19.46, and 0.11 in., respectively, for a total of 70.31 in., which is about 4 in. more than the Halaho or Paishih totals. It is possible that the rainfall intensities

at Paling may have exceeded those of the other two stations for some durations. Unfortunately, no information on the Paling gage or location was available except that it is on the Tamsui River watershed.

The Taiwan maxima were substantially exceeded by those for La Réunion but the differences should not be interpreted as indications of possible differences in their potential maxima from tropical storms. Taiwan is at about 24° N. and La Réunion, about 21° S., but sea surface temperatures during the favored tropical storm seasons tend to be slightly higher near Taiwan. The highest average monthly sea surface temperature in the vicinity of Taiwan is about 82° F. in August and September [5]. For La Réunion, it is about 81° F. in March. Both islands are extremely mountainous with steep slopes, sharply narrowing valleys, and peaks reaching above 10,000 ft. The La Réunion topography is perhaps somewhat the more rugged. Taiwan is, of course, a much larger island than La Réunion, but it is still small enough that it would have little effect on the intensity of tropical storms with centers offshore. Since the surface temperatures of the ocean waters surrounding the two islands appear similar, any differences in their potential maximum rainfall rates would appear attributable to differences in topographic influences or in the rain-producing characteristics of the tropical cyclones affecting the two places. Unfortunately, whether or not such differences exist is unknown.

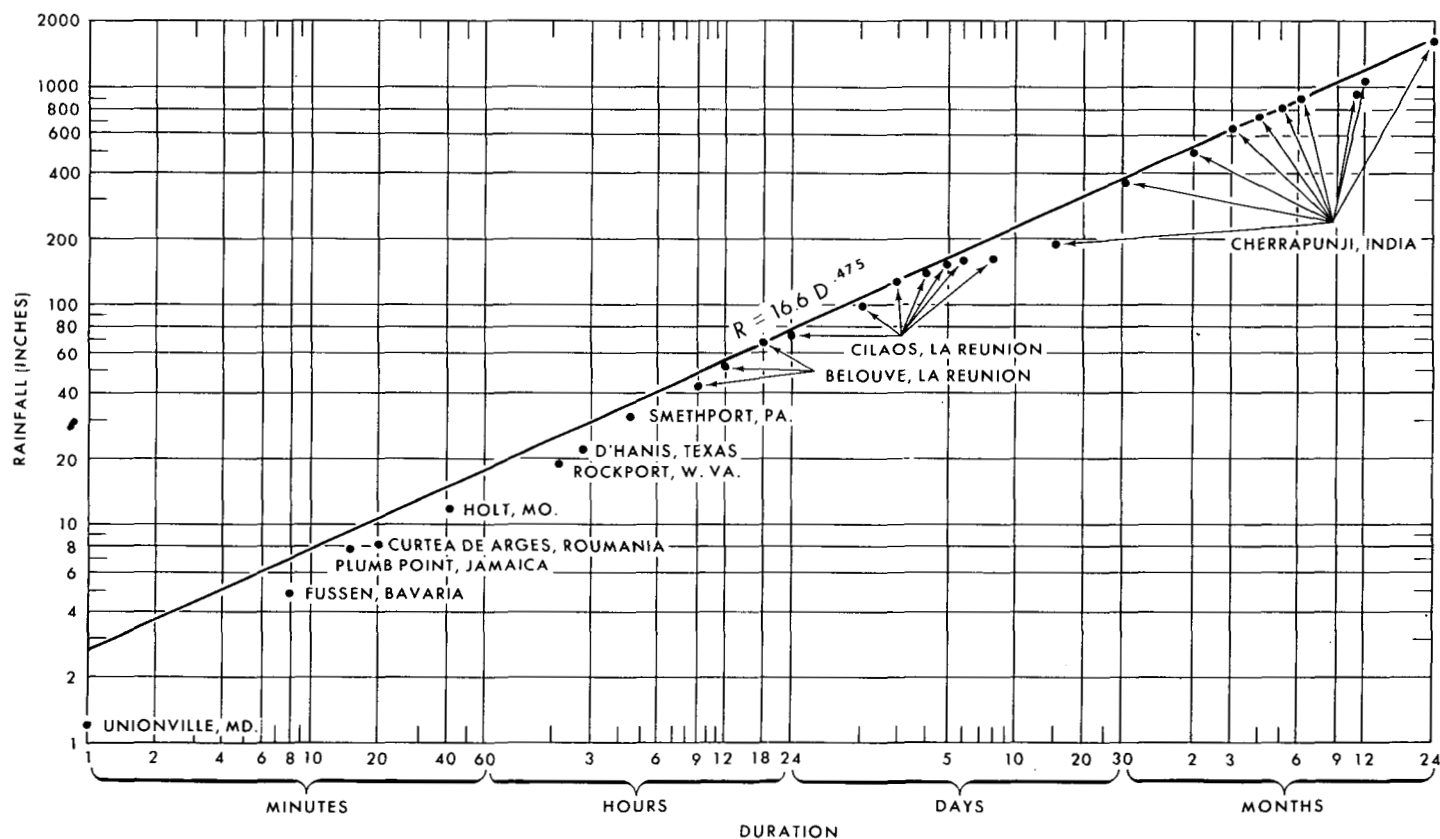


Figure 4.—World's greatest observed point rainfalls.

4. WORLD'S GREATEST OBSERVED POINT RAINFALLS

The maximum amounts measured at Belouve (table 2) and Cilaos (table 4) established new world records for durations from 9 hr. to 8 days. Table 4 provides a comparison of the new record values for 1 to 8 days with the old records they exceeded. The previous record values for durations from 15 through 21 hr. were all exceeded by the 9-hr. amount of 42.79 in. reported for Belouve on February 28, 1964. The old maxima were: 34.50 in. in 15 hr. at Smethport, Pa. on July 17-18, 1942 [6]; 38.00 in. in 18 hr. and 41.7 in. in 21 hr., both at Kadena AFB, Okinawa on September 8, 1956 [7]. These three former world-record values were also exceeded by the Paishih rainfall (table 3).

The revised list of the world's greatest rainfalls for durations from 1 min. to 2 yr. is presented in table 5. These amounts plotted against duration on logarithmic paper (fig. 4) delineate a fairly straight line. The envelope curve may be expressed by $R=16.6 D^{0.475}$, where R is rainfall in inches and D is duration in hours.

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TABLE 4.—New and previous world record rainfall values

Duration (days)	New record			Previous record		
	Station	Amt. (in.)	Date	Station	Amt. (in.)	Date
1.....	Cilaos	73.62	3/15-16/52	Baguio, Philippines...	45.99	7/14-15/11
2.....	Cilaos	98.42	3/15-17/52	Bowden Pen, Jamaica.	82.11	1/22-23/60
3.....	Cilaos	127.56	3/15-18/52	Bowden Pen, Jamaica.	99.52	1/22-24/60
4.....	Cilaos	137.95	3/14-18/52	Bowden Pen, Jamaica.	109.79	1/22-25/60
5.....	Cilaos	151.73	3/13-18/52	Silver Hill Plantation, Jamaica.	114.50	11/5-9/09
6.....	Cilaos	159.65	3/13-19/52	Silver Hill Plantation, Jamaica.	122.50	11/5-10/09
7.....	Cilaos	161.81	3/12-19/52	Cherrapunji, India....	131.15	6/24-30/31
8.....	Cilaos	162.59	3/11-19/52	Cherrapunji, India....	135.05	6/24-7/1/31

TABLE 5.—World's greatest observed point rainfalls

Duration	Depth (in.)	Location	Date
1 min.....	1.23	Unionville, Md.....	July 4, 1956
8 min.....	4.96	Füssen, Bavaria.....	May 25, 1920
15 min.....	7.80	Plumb Point, Jamaica.....	May 12, 1916
20 min.....	8.10	Curtea-de-Arges, Roumania.....	July 7, 1889
42 min.....	12.00	Holt, Mo.....	June 22, 1947
2 hr. 10 min.....	19.00	Rockport, W. Va.....	July 18, 1889
2 hr. 45 min.....	22.00	D'Hanis, Tex. (17 mi. NNW).....	May 31, 1935
4 hr. 30 min.....	30.8+	Smethport, Pa.....	July 18, 1942
9 hr.....	42.79	Belouve, La Réunion.....	Feb. 28, 1964
12 hr.....	52.76	Belouve, La Réunion.....	Feb. 28-29, 1964
18 hr. 30 min.....	66.49	Belouve, La Réunion.....	Feb. 28-29, 1964
24 hr.....	73.62	Cilaos, La Réunion.....	Mar. 15-16, 1952
2 days.....	98.42	Cilaos, La Réunion.....	Mar. 15-17, 1952
3 days.....	127.56	Cilaos, La Réunion.....	Mar. 15-18, 1952
4 days.....	137.95	Cilaos, La Réunion.....	Mar. 14-18, 1952
5 days.....	151.73	Cilaos, La Réunion.....	Mar. 13-18, 1952
6 days.....	159.65	Cilaos, La Réunion.....	Mar. 13-19, 1952
7 days.....	161.81	Cilaos, La Réunion.....	Mar. 12-19, 1952
8 days.....	162.59	Cilaos, La Réunion.....	Mar. 11-19, 1952
15 days.....	188.88	Cherrapunji, India.....	June 24-July 8, 1931
31 days.....	366.14	Cherrapunji, India.....	July 1861
2 mo.....	502.63	Cherrapunji, India.....	June-July 1861
3 mo.....	644.44	Cherrapunji, India.....	May-July 1861
4 mo.....	737.70	Cherrapunji, India.....	April-July 1861
5 mo.....	803.62	Cherrapunji, India.....	April-Aug. 1861
6 mo.....	884.03	Cherrapunji, India.....	April-Sept. 1861
11 mo.....	905.12	Cherrapunji, India.....	Jan.-Nov. 1861
1 yr.....	1041.78	Cherrapunji, India.....	Aug. 1860-July 1861
2 yr.....	1605.05	Cherrapunji, India.....	1860-1861

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